EA417
Flight Test IIB

Determination of Climb Airspeed — Sawtooth Climb Method

I. *Purpose*

To determine, at the test altitude, the maximum rate of climb and the airspeed at which it occurs.

II. *References*

1. Dommasch et al., “Airplane Aerodynamics”, pp. 289–291.
2. Hurt, H. H., Jr., “Aerodynamics for Naval Aviators”, pp. 150–155.
3. Flight Test IIA, Drag Polar From Glide Sink Rates.

III. *Background and Theory*

The rate of climb at constant airspeed is directly proportional to the thrust power available in excess of that required to maintain steady level flight. Thrust power available and thrust power required both vary with airspeed. Therefore, at a given altitude and aircraft gross weight, there is an airspeed where the maximum excess thrust power occurs and the maximum rate of climb is obtained. The sawtooth climb method is a series of short climbs at various airspeeds through a specific altitude. A plot of rate of climb as a function of airspeed yields the maximum rate of climb airspeed at that specific altitude.

Rate of climb, like rate of descent, varies with gross weight and air density. The variation caused by change in weight occurs because a lighter airplane climbs more rapidly at the same excess thrust horsepower; and more excess thrust horsepower is available because a lighter airplane requires less power to maintain steady level flight.

The effects of changes in air density are twofold. First, it is necessary to correct the observed rate of climb for the same reason that it is necessary to correct the rate of descent. Because both the airspeed indicator and altimeter are pressure measuring instruments calibrated on the basis of standard density, corrections are made for nonstandard density. Second, the thrust horsepower available is a function of density.

IV. *Generalized Climb Rate Curves*

To standardize the data to reference weight on a standard day, the equations developed in the discussion of gliding flight are used. In addition, it is necessary to correct the power available for nonstandard conditions.

First, it is necessary to find the calibrated airspeed corrected for nonstandard weight. Recall that

$$\mathrm{CAS}_W = \mathrm{CAS}_T \sqrt{\frac{W_{\mathrm{STD}}}{W_T}} \qquad (2-1)$$

where the subscripts STD and T indicate standard and test conditions, respectively.

Assuming the aircraft altimeter is set to 29.92 in Hg (pressure altitude), the density correction to the rate of climb is given by

$$\left(\mathrm{R/C}\right)_0 = \left(\mathrm{R/C}\right)_T \sqrt{\frac{T_T}{T_{\mathrm{STD}}}} \qquad (2-2)$$

If the density is nonstandard, BHP is corrected by using engine performance tables or graphs.

If the OAT (Outside Air Temperature) is *below* standard temperature, the engine produces additional power; while if it is *above* standard temperature less power is produced. Specific values are given on engine performance graphs or in engine performance tables.

The change in thrust horsepower available is then

$$\Delta\text{THP}_{\text{avail}} = \eta_p \Delta\text{BHP}$$

where η_p is the propeller efficiency at the airspeed and altitude for each data point.

Density changes also affect the thrust produced by the propeller. In general, from propeller theory we have

$$\text{Thrust} = \rho A V \,\Delta V \qquad (2-3)$$

Therefore

$$\frac{(\text{Thrust})_{\text{STD}}}{(\text{Thrust})_T} = \frac{\rho_{\text{STD}}}{\rho_T} = \frac{T_T}{T_{\text{STD}}} \qquad (2-4)$$

or

$$(\text{Thrust})_T = (\text{Thrust})_{\text{STD}}\left(\frac{T_{\text{STD}}}{T_T}\right)$$

The change in available thrust is then

$$\Delta(\text{Thrust}) = (\text{Thrust})_{\text{STD}} - (\text{Thrust})_T = (\text{Thrust})_{\text{STD}}\left(1 - \frac{T_{\text{STD}}}{T_T}\right)$$

The corresponding change in thrust power available is

$$\Delta(\text{THP})_{\text{avail}} = \text{TAS }(\text{Thrust})_{\text{STD}}\left(1 - \frac{T_{\text{STD}}}{T_T}\right)$$

and because $\text{TAS }(\text{Thrust})_{\text{STD}} = (\text{THP})_{\text{STD}} = \eta_p(\text{BHP})_{\text{STD}}$

$$\Delta(\text{THP})_{\text{avail}} = \eta_p(\text{BHP})_{\text{STD}}\left(1 - \frac{T_{\text{STD}}}{T_T}\right) \qquad (2-5)$$

The change in rate of climb of a standard weight airplane resulting from both of these density effects is given by

$$\Delta\left({}^{\text{R}}\!/_{\text{C}}\right) = \frac{\eta_p}{W_{\text{STD}}}\left[\Delta\text{BHP} + (\text{BHP})_{\text{STD}}\left(1 - \frac{T_{\text{STD}}}{T_T}\right)\right] \qquad (2-6)$$

Defining the rate of climb corrected for density effects on power available as $({}^{\text{R}}\!/_{\text{C}})_{PC}$, we have

$$\left({}^{\text{R}}\!/_{\text{C}}\right)_{PC} = \left({}^{\text{R}}\!/_{\text{C}}\right)_0 + \Delta\left({}^{\text{R}}\!/_{\text{C}}\right)$$

The effect of the nonstandard weight on the rate of climb is the same as on the rate of sink. Recalling our previous result, we have

$$\left({}^{\text{R}}\!/_{\text{C}}\right)_{\text{STD}} = \left({}^{\text{R}}\!/_{\text{C}}\right)_{PC}\sqrt{\frac{W_{\text{STD}}}{W_T}} \qquad (2-7)$$

In summary, the generalized equations are

$$\left({}^{\mathrm{R}}\!/\mathrm{C}\right)_0 = \left({}^{\mathrm{R}}\!/\mathrm{C}\right)_T \sqrt{\frac{T_T}{T_{\mathrm{STD}}}} \tag{2-8}$$

$$\Delta\left({}^{\mathrm{R}}\!/\mathrm{C}\right) = \frac{\eta_p}{W_{\mathrm{STD}}}\left[\Delta\mathrm{BHP} + (\mathrm{BHP})_{\mathrm{STD}}\left(1 - \frac{T_{\mathrm{STD}}}{T_T}\right)\right] \tag{2-9}$$

$$\left({}^{\mathrm{R}}\!/\mathrm{C}\right)_{PC} = \left({}^{\mathrm{R}}\!/\mathrm{C}\right)_0 + \Delta\left({}^{\mathrm{R}}\!/\mathrm{C}\right) \tag{2-10}$$

$$\left({}^{\mathrm{R}}\!/\mathrm{C}\right)_{\mathrm{STD}} = \left({}^{\mathrm{R}}\!/\mathrm{C}\right)_{PC} \sqrt{\frac{W_{\mathrm{STD}}}{W_T}} \tag{2-11}$$

V. *Procedure*

At the test altitude set RPM at 2500 and MAP to 25 in Hg and adjust mixture for best power. Stabilize the aircraft in a steady climb at airspeeds of 90, 100, 110, 120, 125 and 130 kts on a heading perpendicular to the wind direction at the test altitude. At 500 ft below test altitude establish the aircraft in a steady climb at the test airspeed and climb to 500 feet above the test altitude.

Students shall:

1. Prior to flight, record aircraft tachometer reading and fuel quantity.
2. Determine aircraft weight.
3. Insure that 29.92 in Hg is set in the Kohlsman window of the altimeter.
4. During climbs, time the climb through 1000 feet at 100 foot intervals with the stopwatch. Record tach time and OAT at 500 ft below the reference altitude, at the reference altitude, and 500 ft above the reference altitude. Record RPM and MAP at the test altitude. Record the rate of climb indicated on the Vertical Speed Indicator at 500 feet below, at and 500 feet above the test altitude.

VI. *Flight test report requirements*

Determine and plot:

a. To validate the data, plot altitude vs time for each of the runs.

b. $({}^{\mathrm{R}}\!/\mathrm{C})_T$ as a function of IAS.

c. $({}^{\mathrm{R}}\!/\mathrm{C})_{\mathrm{STD}}$ as a function of CAS_W.

d. Airspeed for best rate of climb.

e. Airspeed for the best angle of climb.

f. By reference to rate-of-climb tests at other altitudes, find the airspeed for best rate of climb at sea level.

g. Compare the flight test results to those predicted using the values of the Oswald efficiency factor, e, and the equilvalent flat plate area, f, determined from Flight Test 1.

Include a set of detailed sample calculations. Use any run you desire.